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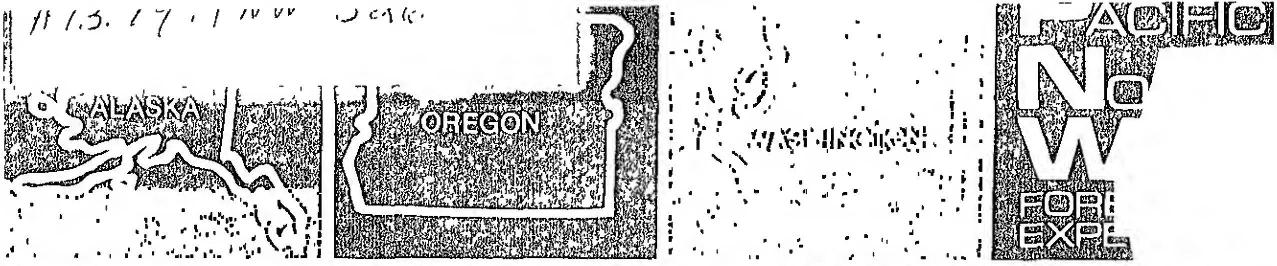

USDA FOREST SERVICE RESEAR

PNW-326 December 1978

Effects of Defoliation by Douglas-fir Tussock Moth on Timing and Quantity of Streamflow

by

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ABSTRACT

Streamflow data from three watersheds in the Blue Mountains of Oregon were tested for changes in annual runoff, summer runoff, and peak discharge following the defoliation in 1972 and 1973 caused by the Douglas-fir tussock moth. Annual runoff from the Umatilla River watershed in 1974 was 13.2 cm greater than the predicted value and 2.5 cm greater than the end point 95-percent confidence band for the baseline data. No changes in runoff were detected on the North or South Fork of the Walla Walla River. Defoliation was more extensive on the Umatilla drainage.

KEYWORDS: Runoff -)vegetation, insect damage (-forest, defoliation damage, Douglas-fir tussock moth, *Orgyia pseudotsuga*.

Acknowledgment

The work leading to this publication was funded in part by the USDA Douglas-fir Tussock Moth Expanded Research and Development Program.

INTRODUCTION

The purpose of the research reported in this paper was to determine the effect of defoliation by the Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough) on annual runoff, seasonal runoff, and peak discharge from major drainage systems. This information is necessary for a complete evaluation of the moth outbreak on the affected ecosystems. If discharge rates during spring runoff increase substantially, culverts and bridges could be destroyed and stream habitat damaged for aquatic life. On the other hand, an increase in flow during late summer could enhance aquatic habitat and provide more water for irrigation agriculture, provided water quality remains acceptable.

The water balance of a drainage basin can be expressed mathematically as:

$$R = P - (T + I + E) \pm S$$

where R is runoff, P is precipitation, T is transpiration, I is interception, E is evaporation from land surfaces, and S is soil moisture storage. The units are depth over the drainage area and the time period usually is a year or a season.

It is generally agreed that vegetation reduction has no measurable effect on precipitation amounts (McDonald 1960), but transpiration and interception losses are reduced. Evaporation losses increase somewhat because of increased soil exposure to solar energy. Soil moisture storage increases and remains at a higher level than before vegetation reduction. The net effect of complete vegetation removal, whether by natural causes or by forest harvest, is an increase in annual runoff. A partial reduction may or may not produce an increase in runoff, depending on several factors including the percentage of vegetation reduction and the balance between soil moisture storage and energy available for evaporation. A more detailed discussion of the soil moisture-energy-runoff relationships as they apply to this study will be presented later.

PREVIOUS WORK (NATURAL DEFORESTATION)

One of the most extensive insect outbreaks in this country occurred in Colorado between 1941 and 1946. The Engelmann spruce beetle (*Dendroctonus rufipennis* (Kirby)) killed practically all of the Engelmann spruce and lodgepole pine growing on 585 km^2 within the White River watershed (Love 1955). Love's analysis of annual water yield changes indicated that about 5 cm of extra water per unit area were produced by the White River drainage after the insect attack. A later analysis by Bethlahmy (1975) indicated that even 25 years after the attack, runoff was still about 10 percent greater than the natural values. Apparently the denuded forest was extremely slow in recovering.

Tropical storms sometimes travel along the eastern part of North America and cause considerable damage to forested areas. A hurricane in 1938 was one of the most destructive on record as far as the forest is concerned. It uprooted and broke off vast numbers of trees in two New England watersheds. Patric (1974) analyzed historical flow records and concluded that annual runoff increased about 12.5 cm per unit area during the first year after the hurricane. Because of the rapid recovery of hardwood forests, runoff returned to normal after only 5 years.

Wildfire is perhaps responsible for destroying more vegetation in western forests than any other natural cause. In 1970, about 485 km^2 of forested land in north central Washington were blackened by wildfire. Helvey (1972) reported average water yield increases of 8.4 cm per unit area (50 percent) and water temperature increases of 5.5° C on the Entiat Experimental watersheds during the 1st year after the fire. Klock (1972) found that water in the soil profile was 11.5 cm greater in September 1971 than in September 1970, indicating that a large part of the transpiration savings were retained in the soil profile. Water yield increases in later years were even greater (Helvey 1973), but record precipitation amounts prevented an accurate determination of the effect of vegetation reduction alone. The burned areas became extremely sensitive to precipitation input, and runoff rates were much higher than before the fire. Debris flows were common during the second postfire year.

THE STUDY AREA

The study area, located in northeastern Oregon and southeastern Washington, is part of the Blue Mountains. Topography of the Blue Mountains varies from undulating plateaus to steep rugged mountains reaching to 2 500 m elevation. Vegetation varies with elevation i.e., big sagebrush (*Artemisia tridentata* Nutt.) occupies the lowest levels; and as elevation increases, vegetation changes to ponderosa pine (*Pinus ponderosa* Laws.), to Douglas-fir (*Pseudotsuga mensiesii* (Mirb.) Franco), to subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and finally to vegetation typical of above timberline conditions (Hall 1973).

Precipitation is primarily a cool season phenomenon. Maritime storms cross the mountains from west to east in the fall and winter. Orographic lifting cools the moist air and causes precipitation to fall. Average annual precipitation is 38 cm at the lowest elevations; over 138 cm at the upper slopes. Approximately 80 percent of the total annual precipitation falls between October 1 and May 31. At the upper slopes, a snowpack usually begins to form by late November. It increases in depth and water content until late March or early April. Snowmelt begins on lower slopes with south exposure in February, and the snow line advances to upper elevations. Complete snowmelt varies from year to year depending on maximum snow accumulation and air temperature in the early Spring months. The last snow usually is melted by early June.

Runoff patterns are typical of areas where snow is the dominate form of precipitation. Figure 1 illustrates average monthly flow rate for the Umatilla River. Runoff increases during the fall months because of increased rainfall at the lower elevations. Rapid snowmelt in March, April, and May produces maximum discharge rates during these months. Flow rates decrease during summer months because evapotranspiration demand greatly exceeds rainfall input.

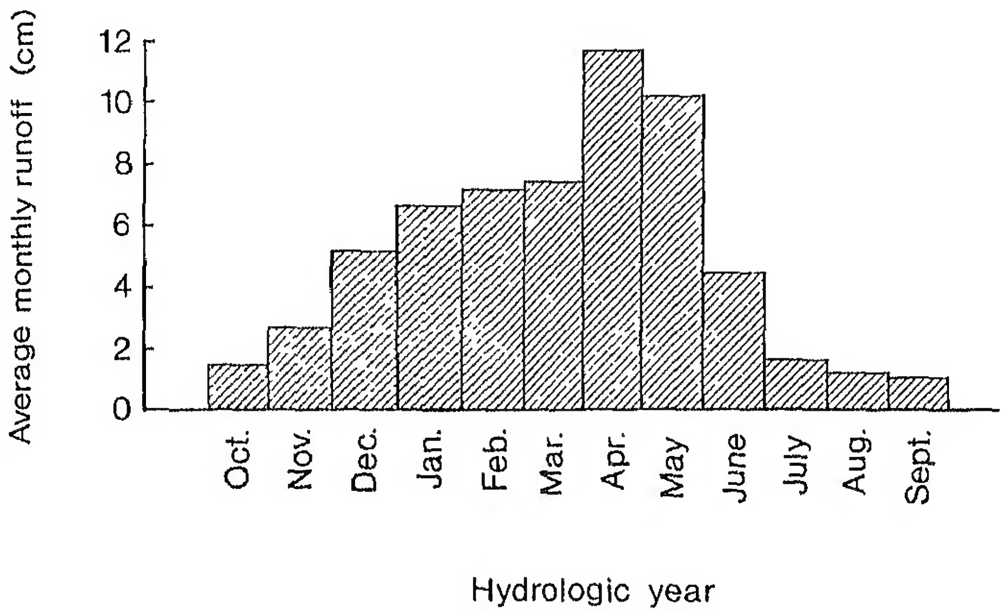

Figure 1.--Average monthly runoff from the Umatilla River.

METHODS

Runoff changes caused by vegetation reduction usually are determined by the paired watershed technique. That is, runoff from two or more watersheds is measured during a 3- to 10-year calibration period while the watersheds remain undisturbed. The watersheds are purposely chosen for their similarity in vegetation, soils, and geomorphology. One watershed is designated the control, and regression equations are developed during calibration so that runoff from each watershed can be accurately predicted from values measured on the control unit. After the watersheds are satisfactorily calibrated, the vegetation on one or more units is reduced by a predetermined amount while the control unit remains undisturbed. Runoff changes due to vegetation reduction are calculated by subtracting the value predicted by the calibration regression from the measured value. If this absolute difference is significantly greater than zero at the accepted level of probability, the change is attributed to reduced vegetation levels.

A variation of the paired watershed technique was used in this study. Instead of the typical experimental watershed of 40-400 hectares, watersheds used in this study range up to 340 km^2. Although

small drainages would have been more desirable, no watersheds within the defoliated area had been monitored for runoff before defoliation began. The only alternative was to choose watersheds within the defoliated area for which the U.S. Geological Survey had collected and published discharge records.

A map indicating areas of tussock moth defoliation in the Blue Mountains was supplied by the Umatilla National Forest. Insect damage was identified on this map as heavy mortality in 1972, heavy mortality in 1973, top killing in 1973, and light defoliation in 1973. There is some indication that the damage was not as severe as the initial survey indicated. After the insects were killed with chemical spray, some trees, which at first appeared to be heavily damaged, put out a new set of needles and fully recovered.

Three watersheds which were partially defoliated and which have been gaged by the Geological Survey were chosen for study (fig. 2).

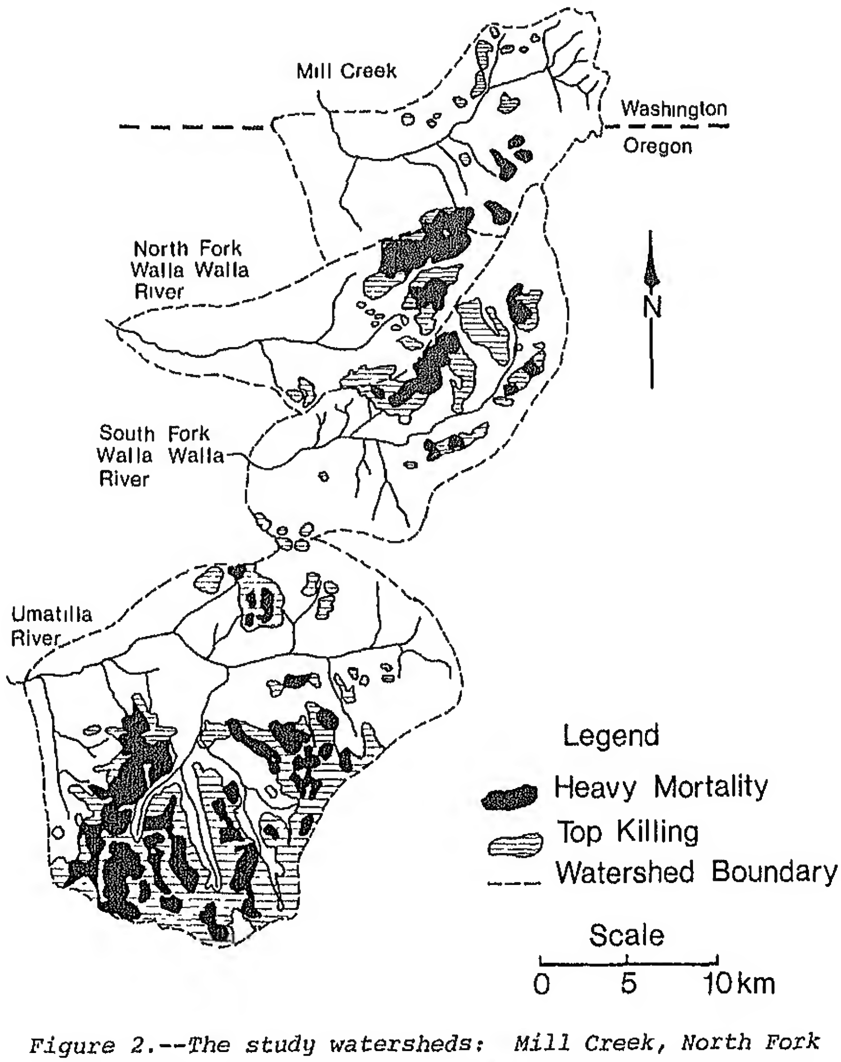

Figure 2.--The study watersheds: Mill Creek, North Fork Walla Walla River, South Fork Walla Walla River, and the Umatilla River.

These are (1) the North Fork of the Walla Walla River (113 km^2), the South Fork of the Walla Walla River (169 km^2), and the Umatilla River (352 km^2). Runoff from Mill Creek (160 km^2), was used as control data since defoliation was slight on this drainage (Hicks 1977). A dot grid was used to estimate the percentage of total watershed area in each defoliation category listed above.

The analytical procedure used here is illustrated by the following example: (1) Annual runoff volume from the Umatilla River and Mill Creek was tabulated for each year between 1950-1971. (2) A scatter diagram was plotted in which runoff from the Umatilla Basin (partially defoliated) was the dependent variable (Y) and runoff from Mill Creek was the independent variable (X). (3) A linear regression was computed and the least squares line drawn on the scatter diagram. (4) The location of several points on the 95-percent confidence limits was calculated for the individual points on the scatter diagram using the equation:

$$\hat{Y} \pm t \sqrt{(\text{Residual MS})\left\{(1 + \frac{1}{N} + \frac{(Xo - \bar{X})^2}{\Sigma x^2}\right\}}$$

(The interested reader is referred to Freese (1967) for a discussion of the computation and interpretation of the confidence limits.) (5) A smooth curve was constructed through the confidence limit points. (6) Measured runoff from the Umatilla River during each year after defoliation was plotted on the scatter diagram as a function of concurrently measured runoff from Mill Creek. If a value after defoliation was inside the confidence bands, we concluded that runoff during that year was not significantly different from predefoliation values. If the value was outside the confidence bands, we concluded that runoff was different from the relationship before defoliation; and we speculated on the cause of the difference.

The same steps as outlined above were followed for annual runoff, seasonal runoff (April-June, July-September, and September-November), and peak discharge from each of the partially defoliated basins.

Personnel in National Forest Administration were contacted for information on past insect outbreaks and for timber harvest records. According to these records, there has been no serious insect defoliation in any of the drainages in recent times; but timber harvest has proceeded on each watershed since 1950. There is no evidence to indicate that logging on one drainage was enough greater than on the others to cause measurable changes in water yield. Thus, runoff differences between watersheds before the tussock moth outbreak are the result of natural factors and not man's activity. The control watershed (Mill Creek) serves as a municipal watershed for the city of Walla Walla, Washington. The city diverts about 0.62 m^3/sec at a point 4 miles above the gaging station for municipal use (U.S. Geological Survey 1975). No correction of the records was attempted for this diversion--it was considered a constant value from year to year. No logging is permitted on the headwaters of Mill Creek.

RESULTS AND DISCUSSION

Table 1 lists the estimated area percentages affected by the insect in 1972 and 1973. It appears from this tabulation that the Umatilla drainage was more severely defoliated than the other two. If we assume that top killing removes about half of the transpiring surface of a tree and heavy mortality removes all surfaces, the Umatilla drainage suffered a 25-percent reduction in transpiring surfaces in 1972 and 1973 combined. The North Fork of Walla Walla River lost about 16 percent of its foliage surfaces and the South Fork about 13 percent. Light defoliation in 1973 was about the same on all three watersheds at 20 percent. The most severe damage occurred along ridgetops and upper slopes where soil moisture usually is more limiting than on lower slopes. This is an important factor because vegetation removal from upper slopes would be expected to influence runoff less than an equal reduction on lower slopes. The reason for this conclusion will be discussed later.

Table 1--*Douglas-fir Tussock Moth Area-Activity in three drainages of the Blue Mountains of Oregon*

Activity	North Fork Walla Walla	South Fork Walla Walla	Umatilla
	- - - - - - - -	-Percent - - - -	- - - - -
Heavy mortality in 1972	8	4	1
Heavy mortality in 1973	1	2	10
Top killing in 1973	14	14	30
Light defoliation in 1973	20	21	20

Annual runoff from the Umatilla River is plotted in figure 3 as a function of annual runoff from Mill Creek. Ninety-five-percent confidence bands are included, as recommended by Freese (1967), to illustrate variability in the data before insect defoliation began. Data points after defoliation are identified on the figure by the year of measurement.

Our statistical analysis indicated no effect of defoliation on runoff in 1972 when the insect outbreak began, nor in 1973 when annual precipitation was extremely low. In 1974, however, when about 25 percent of the transpiring surface was removed and annual precipitation was near the maximum ever recorded for the study area, annual runoff was 13.2 cm greater than the predicted value (fig. 3). Although this value is 2.5 cm greater than the upper end point of the confidence band, it should be interpreted with caution because the measured value on Mill Creek in 1974 was 22 cm greater than the largest value in the calibration data. One basic assumption of regression analysis is that

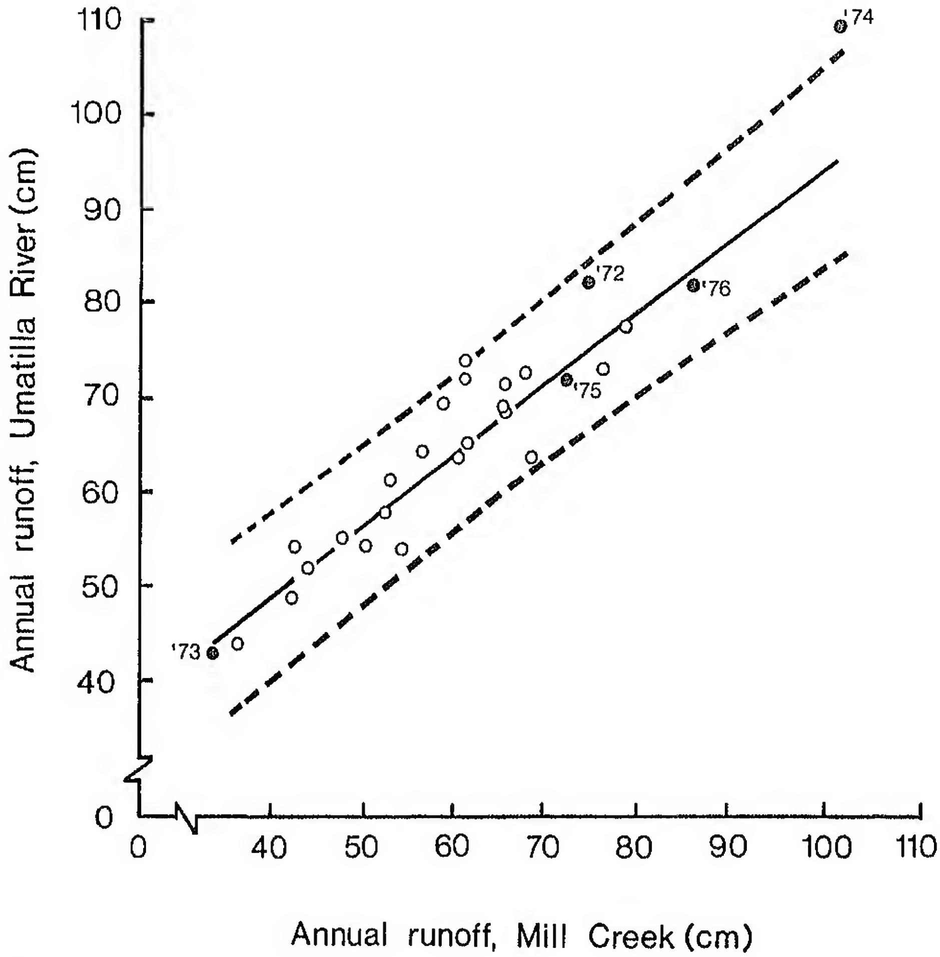

Figure 3.--Annual runoff from the Umatilla River compared to annual runoff from Mill Creek. The number beside each solid dot is the year of measurement for that point.

prediction should be restricted to the range of data used to compute the regression. Although runoff in 1974 was greater than the upper end point of the 95-percent confidence band, the uncertainty associated with the confidence band location prevents a definitive statement about the effects of defoliation on runoff in 1974.

In 1975 and 1976 when precipitation was slightly above average, runoff from the Umatilla River was near the predicted value. If the increase in 1974 was due to decreased evapotranspiration resulting from defoliation, it seems that increased runoff would have continued into 1975 and 1976. It could be that tree recovery from the initial defoliation (greenup) was sufficient to restore transpiration losses to a level which approximated natural conditions.

The next step in the analysis was to test for seasonal changes in runoff from the Umatilla River associated with the defoliation. Tests

were made on peak discharge, and total runoff during snowmelt (April-June), during summer months (July-September), and during the autumn months (September-November). The test indicated no significant change during snowmelt or the summer months. Runoff during the autumn months of water year 1974, however, was significantly greater than the predicted value. Actual runoff during these months was 23.6 compared to the predicted value of 17.8 cm. This was about 1.3 cm greater than the upper end point of the confidence band (95-percent level) for the baseline data.

Peak discharge data were highly variable, and no change could be detected. This result was expected because even on small watershed studies where runoff is measured much more accurately than is possible on rivers, complete clearcutting produces only small increases in peak flow rates (Harr 1976).

Plottings of annual runoff for the North Fork and the South Fork of the Walla Walla River revealed no detectable change in runoff after the defoliation (figs. 4 and 5).

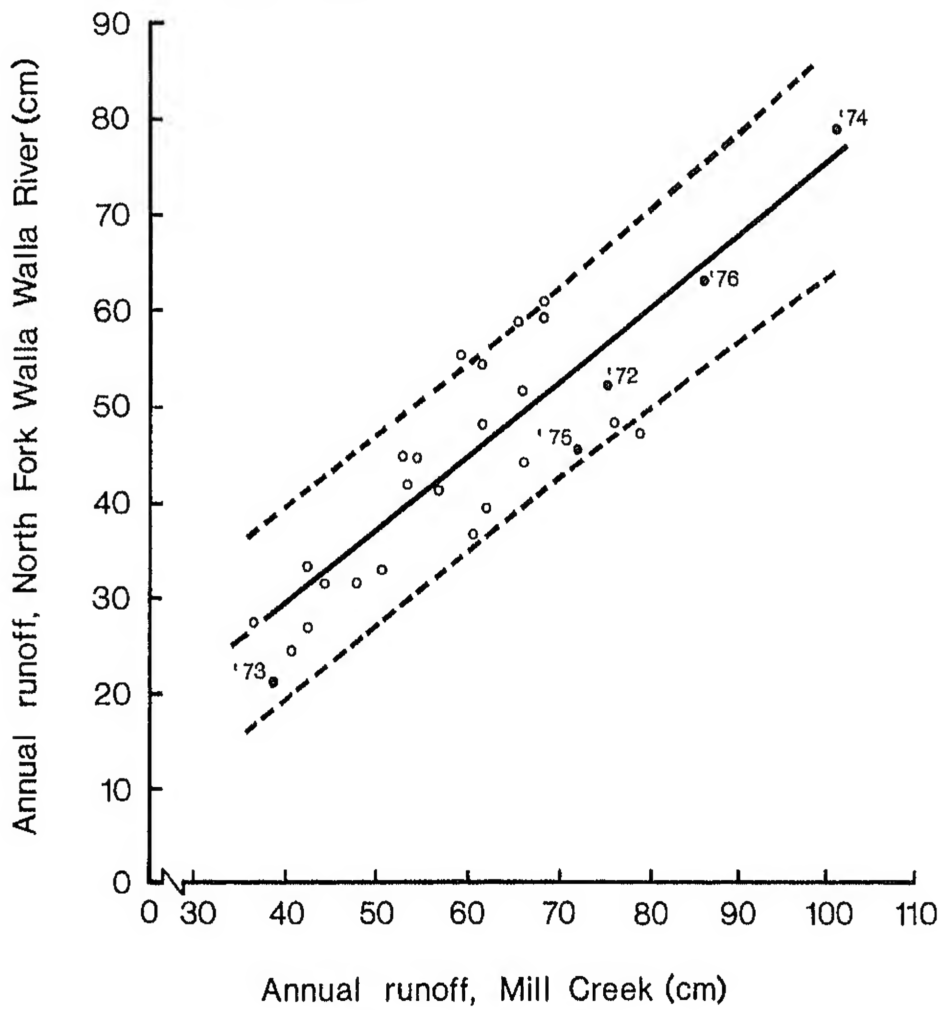

Figure 4.--Annual runoff from the North Fork of Walla Walla River compared to annual runoff from Mill Creek. The number beside each solid dot is the year of measurement for that point.

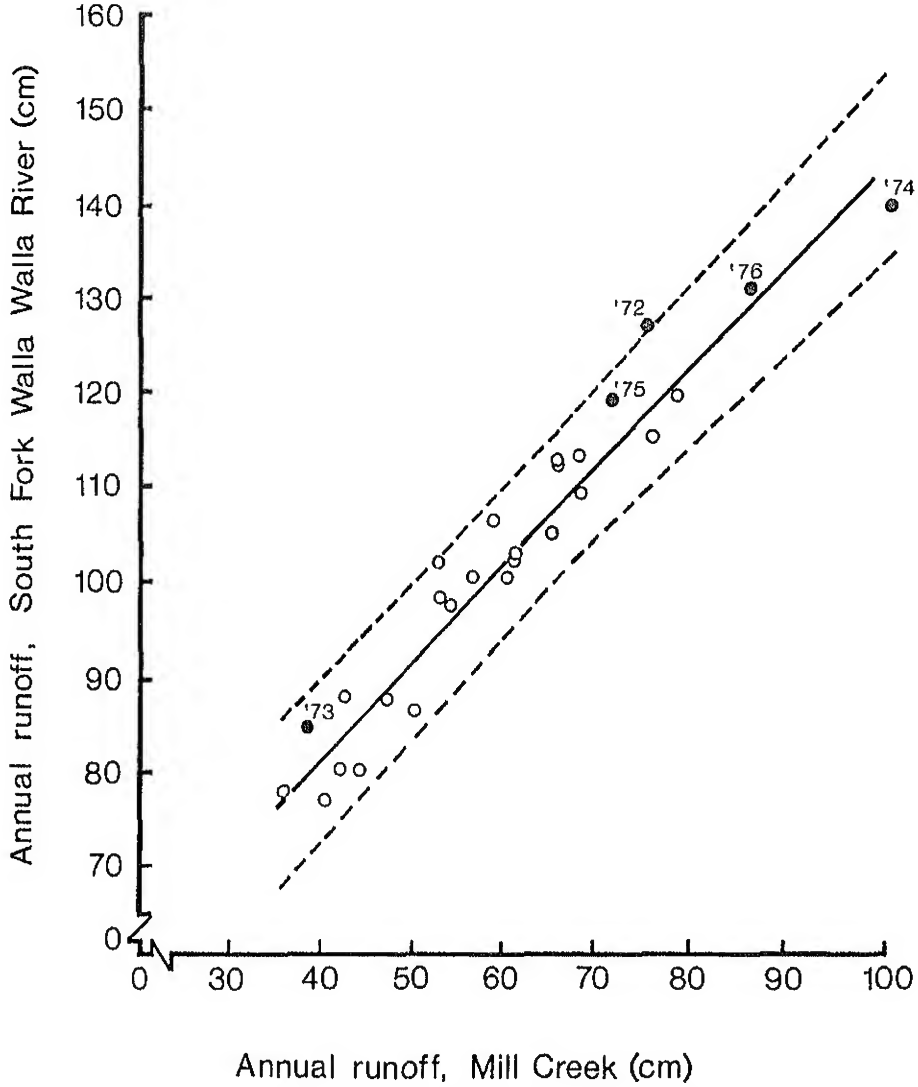

Figure 5.--Annual runoff from the South Fork of Walla Walla River compared to annual runoff from Mill Creek. The number beside each solid dot is the year of measurement for that point.

From these and previously published results, it appears that at least three factors are involved in determining the amount of annual runoff increase following vegetation reduction. These are (1) percent of the total drainage area deforested, (2) location of the deforested area with respect to the stream channel, and (3) current annual precipitation as a percent of the longterm mean value. Hibbert (1965) concluded from his world wide literature survey that at least 20 percent of a basin must be deforested before runoff significantly increases. Hibbert gave two reasons for this result: First, removing a smaller percentage of vegetation, such as thinnings, allows remaining trees to increase their water use rates, especially in areas such as eastern

Oregon where potential evapotranspiration in late summer usually exceeds available water supplies. Second, an increase must be larger than the experimental error associated with the baseline data before a statistically significant change is indicated. Accuracy of the runoff data used in this analysis is rated "good" by the U.S. Geological Survey. This means that about 95 percent of the daily discharge values are within 10 percent of the true value. Therefore, an increase smaller than 10 percent in this study cannot be detected.

In areas where potential evapotranspiration exceeds available soil moisture supplies, removing riparian vegetation has a larger effect on runoff than an equal area of cutting on upper slopes. For example, Rowe (1963) reported an increase in flow equal to 35 cm over the area treated when riparian vegetation was removed from a drainage in southern California. On the other hand, the riparian effect could not be demonstrated in western North Carolina where precipitation during all seasons exceeded potential evapotranspiration (Helvey and Hewlett 1962).

Bethlahmy (1974) showed that increases in runoff after deforestation are directly related to current annual precipitation, i.e., increases were much larger during wet than during dry years. Therefore, the indicated runoff increase in 1974 from the Umatilla River probably was caused by insect defoliation because this was the year of maximum defoliation and an ample moisture supply.

SUMMARY

The trees on 16 percent of the North Fork of Walla Walla River Basin, 13 percent of the South Fork of Walla Walla River Basin, and 25 percent of the Umatilla Basin were defoliated by Douglas-fir tussock moth between 1972 and 1974. The integrated effects of this natural activity on the water balance were determined by regression analysis of runoff data. Runoff records from an adjacent basin (Mill Creek) which received only minor activity, served as control data.

Because of the great variability in runoff data before defoliation began, a rigorous test of runoff changes caused by insect activity could not be made. Annual runoff from the Umatilla River in 1974, however, was 13.2 cm greater than the predicted value and 2.5 cm greater than the upper end point of the 95-percent confidence band for the baseline data.

No changes in annual runoff were detected from the lightly defoliated basins, and no effect of defoliation on peak discharge was detected on any of the watersheds.

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